

Use of Handheld Computers in Medical Education

A Systematic Review

Anna Kho, MD, Laura E. Henderson, MS, Daniel D. Dressler, MD, MSc,
Sunil Kripalani, MD, MSc

Emory University School of Medicine, Atlanta, GA, USA.

BACKGROUND: Over the past decade, handheld computers (or personal digital assistants [PDAs]) have become a popular tool among medical trainees and physicians. Few comprehensive reviews of PDA use in medicine have been published.

OBJECTIVE: We systematically reviewed the literature to (1) describe medical trainees' use of PDAs for education or patient care, (2) catalog popular software applications, and (3) evaluate the impact of PDA use on patient care.

DATA SOURCES: MEDLINE (1993 to 2004), medical education-related conference proceedings, and hand search of article bibliographies.

REVIEW METHODS: We identified articles and abstracts that described the use of PDAs in medical education by trainees or educators. Reports presenting a qualitative or quantitative evaluation were included.

RESULTS: Sixty-seven studies met inclusion criteria. Approximately 60% to 70% of medical students and residents use PDAs for educational purposes or patient care. Satisfaction was generally high and correlated with the level of handheld computer experience. Most of the studies included described PDA use for patient tracking and documentation. By contrast, trainees rated medical textbooks, medication references, and medical calculators as the most useful applications. Only 1 randomized trial with educational outcomes was found, demonstrating improved learning and application of evidence-based medicine with use of PDA-based decision support software. No articles reported the impact of PDA use on patient outcomes.

CONCLUSION: Most medical trainees find handhelds useful in their medical education and patient care. Further studies are needed to evaluate how PDAs impact learning and clinical outcomes.

KEY WORDS: handhelds; personal digital assistants (PDAs); medical trainees; medical education.

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With the increasingly complex and vast amount of information presented in medical education today, handheld computers have proven to be a valuable resource for medical students, residents, and faculty physicians. Also known as personal digital assistants (PDAs), handheld computers offer a powerful and portable means of managing medical information and increasing clinical knowledge. Handhelds may be used in the classroom for formal instruction, with such novel applications as conducting real-time surveys via wireless units.¹ At the bedside, they can be used for clinical education by facilitating calculation of clinical prediction rules, checking for drug interactions, and consulting references to expand dif-

ferential diagnoses.² Handheld computers are also becoming an important part of patient care and documentation through electronic order entry and patient tracking applications.³

As the release of the Apple Newton in 1993 and Palm Pilot in 1996, PDAs have developed increasing functionality, with decreasing size and weight.⁴ Most current devices use either the Palm operating system (OS) or Windows, which offer high-resolution color displays, and provide sufficient memory to store large amounts of data or reference material. Palm OS devices, in general, have a longer battery life, smaller size, and larger number of medical applications. Pocket PCs using Windows have larger screens, the ability to run multiple programs simultaneously, and natural handwriting recognition software.⁵ Wireless devices allow users to access electronic mail and the internet remotely, creating virtually limitless access to medical resources or other information.

Because of the rapid advances in this field, it may be difficult for medical educators to remain abreast of the current and potential uses of handheld computers. While a number of useful reviews have been published, most have been narrative and do not report the most recent research, such as that presented at medical education conferences.^{2-4,6-14} We performed a systematic review of the literature to (1) update educators and trainees on uses of handheld computers in medical education, (2) develop a list of popular software packages, and (3) examine the impact of PDA use on patient care.

METHODS

Search Strategy

We searched OVID MEDLINE (1993 to September 2004) using the following broad set of PDA-related medical subject headings (MeSH) and keywords: Computers, Handheld (introduced in 2003, previously indexed as Microcomputers); Microcomputers; Computer-Assisted Instruction; Computer Peripherals; Point-of-Care Systems; PDA\$; palm pilot; handspring; pocket PC; or wireless. Results were combined (using the Boolean term "and") with the following education-related MeSH terms and keywords: exp Education, Medical; Students, Medical; Attitude of Health Personnel; Attitude to Computers; Faculty, Medical; exp Academic Medical Centers; Computer User Training; Educational Technology; medical student\$; resident\$; or residency. These terms were chosen based on MeSH indexing patterns of references known to be relevant and published search strategies of prior handheld computer reviews.^{2,8} Search dates were based on the year of introduction of the first modern handheld computers (1993).⁴ We then hand searched bibliographies of eligible articles and prior reviews. Finally, using the terms PDA, and handheld, we also searched abstracts presented at national meetings of the Society of General Internal Medicine (2001 to 2004), American Medical Informatics Association (2002 to 2004), American Association

Address correspondence and requests for reprints to Dr. Kho: Division of General Medicine, 49 Jesse Hill Jr. Dr. SE, Atlanta, GA 30303 (e-mail: apham@emory.edu).

of Medical Colleges (2002 to 2004), Society of Hospital Medicine (2002 to 2004), and Society of Teachers of Family Medicine (2002 to 2004), contacting authors by electronic mail when necessary to obtain abstracts. An expert in the field reviewed the search results for completeness and accuracy.

Inclusion Criteria and Manuscript Selection

We included English language publications evaluating the use of handheld computers in medical education. Articles describing their clinical use by medical trainees were also included, as this process involves self-directed learning. Given the dearth of randomized or otherwise controlled studies, we deemed eligible any reports presenting original quantitative or qualitative assessment (e.g., trainee attitudes, process measures such as usage statistics, and educational or clinical outcomes). Reports describing use of handheld computers by only practicing physicians, nurses, or allied health students were excluded. However, articles with mixed populations were accepted if they included medical trainees, and results pertaining to the medical trainees were separated when possible.

Three authors (A.K., D.D.D., and S.K.) independently reviewed electronic citations (including title, subject headings, and abstract) for potential inclusion in an unblinded, standardized manner. Discrepancies were resolved by consensus. Two authors (A.K. and L.E.H.) then independently reviewed full text articles selected by the electronic citation review, articles identified by the hand search of references, and abstracts presented at the selected national conferences, to determine final article inclusion. Discrepancies were resolved by discussion with input from a third author (S.K.).

Data Abstraction and Synthesis

Two reviewers (A.K. and L.E.H.) extracted data according to recurring themes. We summarized these findings using tabular techniques and descriptive statistics. Reported analyses were too disparate to be pooled in a meta-analysis.

RESULTS

Search Results

The electronic database search yielded 1,616 citations. After initial screening for eligibility via titles, subject headings, and abstracts, we retrieved 170 articles for a more detailed review. Among these, 46 met the full eligibility criteria. An additional 5 articles were identified by hand searching bibliographies of these eligible articles and prior reviews. Including the 16 unique abstracts selected from conference proceedings, the search identified a total of 67 reports for inclusion in this review (Fig. 1). These articles and abstracts were grouped by study population (e.g., medical students, residents) and also by the following content areas: (1) general attitudes; (2) general use; (3) formal teaching, feedback, and evaluation; (4) clinical education; (5) patient care/documentation; and (6) research uses of PDAs.

Distribution of Included Studies by User Population

Among the 67 included reports, 27 (40%) evaluated handheld computer use among medical students, 25 (37%) evaluated use among residents, and 15 (22%) pertained to a mixed audience of students, residents, fellows, and/or attending physicians. No articles focused solely on handheld use among fellows or attending physicians.

Most reports evaluated more than one aspect of handheld computer use (see Table 1). Among both medical student and resident users, most studies focused on the utility of PDAs for accessing electronic medical resources and for tracking patients, diagnoses, and procedures. Studies with mixed user populations addressed a broader range of PDA applications, including billing and prescription writing. Only 1 study, by McLeod and colleagues, compared trainee and attending physician use of PDAs. They found that trainees were more likely to report frequent use of drug information programs (53% vs 13%, $P < .0001$), medical references (27% vs 5%, $P < .0001$), and medical calculators (26% vs 5%, $P < .0001$), while attendings more commonly used PDAs for administrative purposes (17% vs 5%, $P < .01$).¹⁵

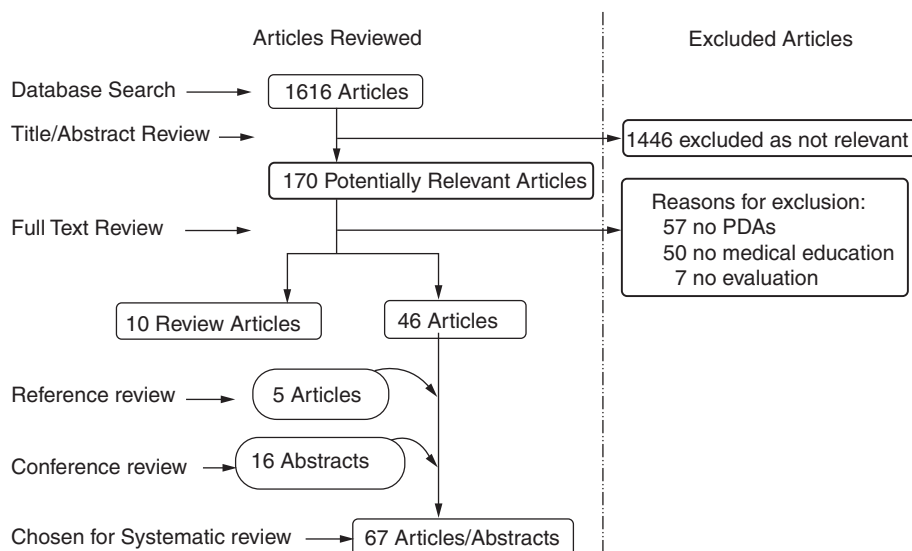


FIGURE 1. Process of article/abstract selection.

Table 1. Distribution of Research Reports by Content Area and Trainee Type

	Students	Residents	Mixed	Total
General attitudes	3	3	3	9
General uses	1	7	8	16
Formal teaching, feedback, evaluation				
Lecture notes		1	2	3
Evaluations	4		2	6
Real-time surveys			1	1
Clinical teaching				
Algorithms/guidelines	1	3	1	5
Calculators	4	6	5	15
Formal educational resources	13	10	10	33
Patient care				
Billing			2	2
Electronic medical records		1	1	2
Order entry		1		1
Documentation		2	2	4
Patient tracking	16	10	8	34
Tracking diagnosis	11	5	1	17
Tracking procedures	3	9	2	14
Prescription writing		1	2	3
Research use			1	1

Because of multiple content areas within a single report, reports may be counted in more than one row.

General Attitudes

The 9 articles evaluating medical trainees' attitudes toward PDA use commonly found that satisfaction correlated with the level of handheld computer experience.¹⁶⁻²⁴ In a qualitative study evaluating 54 physicians' perspectives about PDAs in clinical practice, McAlearney and colleagues identified 4 categories of users—power users (technophiles, used PDAs as much as possible), routine users (regularly used multiple applications in clinical care), niche users (used only 1 application, or only used PDA to keep schedule), and nonusers. While PDA users reported that the devices helped them increase productivity and improve patient care, non-PDA users expressed concern about the reliability, security, and dependency on the device.²⁰ Similar findings were reported by Moore et al.,²³ who found that students who used PDAs perceived them to have greater value than did nonusers. Providing medical trainees with discounted or free PDAs was not consistently associated with development of favorable attitudes toward their use.^{18,21}

Among nonusers of PDAs, 2 categories of barriers were identified by McAlearney and colleagues—those pertaining to personal issues and the device itself. Personal barriers included lack of comfort with technology, poor vision, and a preference for pen-and-paper. Device-related barriers included their small size, limited memory, and poor data-entry interface.²⁰ Others have noted similar disadvantages to PDAs, such as the potential to lose data, slow data entry, and small physical size, while citing as advantages their speed, organization, and ability to store contact information.¹⁹ These studies did not describe whether barriers were more common for Palm OS or Pocket PC devices, although clear differences exist between the 2 platforms.

General Use

Seventeen reports evaluated general use of PDAs among medical trainees.^{15,16,18-32} Most of these studies were conducted at

single institutions, with usage varying widely by site, from 27% to 90%.^{19,25} A national sample survey of pediatricians (not specific to medical education) showed that 35% of respondents used PDAs at work and 40% used PDAs for personal use.¹⁶ Personal digital assistant use was more common among men, trainees, and recent medical school graduates (62% of respondents graduating within the past 5 years reported using a PDA vs 29% of those who graduated more than 5 years ago, $P < .001$).¹⁶ In addition, residents with greater "technology scores" were more likely to use PDAs to access drug databases.²¹ Other studies have also reported greater PDA use among trainees and young physicians,^{15,20} but some have not.^{24,29} In a national survey of family practice residency directors, 30% reported mandatory handheld computer use, and an additional 37% reported less uniform use.²⁷ No study specifically reported on the national prevalence of PDA use in medical education. However, based on the literature reviewed, it appears that approximately 60% to 70% of medical students and residents use handheld computers for education or patient care. Similar rates of use were reported among trainees on both generalist and subspecialist tracks.^{19,27}

Formal Teaching, Feedback, and Evaluation

Personal digital assistants are becoming a valuable tool in the classroom setting for both the teacher and the student, and such use was described in 8 studies reviewed.^{1,20,28,33-37} At some institutions, lecture materials can be downloaded onto a PDA before hand, allowing the student to concentrate on the lecture rather than hastily jotting down notes.^{20,28,33} Personal digital assistants can also be used as a polling tool in the classroom, whereby teachers display multiple-choice questions as a web page, while students respond to these questions using their PDAs and wireless Bluetooth cards.¹ This educational modality provides both interactivity and real-time assessment of students' knowledge.

Handheld computers may also be used for teaching evaluations. One article reported completion rates increasing from 20% to over 80% with a shift from paper to PDA-based evaluations, while simultaneously realizing significant annual cost savings.³³ Torre et al. have used students' real-time PDA-based data collection to evaluate the perceived educational value of specific activities on clinical rotations (e.g., receiving feedback on oral presentations) and their association with educational evaluations.³⁵⁻³⁷ Recording such activities in real-time avoids much of the recall bias associated with monthly evaluations, and electronically harvesting these data from PDAs allows educators to track a variety of parameters with relative ease.

Clinical Education

In clinical settings, medical trainees often use handheld computers as portable resources providing rapid, point-of-care information to guide patient care and augment self-directed learning. Such use of PDAs was described in 33 reports.^{15-33,38-51} We grouped these reports into 3 overlapping subcategories: PDA applications ($N=18$), training in the use of PDAs ($N=18$), and educational outcome studies ($N=1$).

The most commonly accessed applications included medication reference tools (e.g., ePocrates Rx), electronic textbooks (e.g., 5-Minute Clinical Consult), and clinical computational programs (e.g., MedMath and MedCalc).^{15,16,19,22-27,30,32}

Other important tools described in the literature were clinical decision support software, practice guidelines, prediction rules, and physician order sets for common diagnoses.^{39,43,44,46,47,50} Electronic reference users perceived a time savings of about 1 min/encounter compared with traditional references.²⁹

In some cases, clinical resources were provided to medical trainees as part of a curriculum or institutional effort to promote greater use of handheld computers.^{17,18,23,25,28,30,38,39,41–47,49,51} The amount of user training was noted in only a few of these reports and ranged from 1 to 4 hours.^{18,23,30,45,46} Kho et al. developed evidence-based decision support software for common inpatient conditions, instructing students on use of this program and other medical applications through a pair of 1-hour workshops.⁴⁴ Rao described a successful curriculum to introduce handheld computers into a family practice residency through four 1-hour modules.³⁰ In a national survey of family practice residencies, 51% of programs using PDAs offered initial training (mean 1.17 hours, range 1 to 12 hours), and 31% of these provided ongoing training (mean 0.9 h/y, range 1 to 24 h/y).²⁷ Van Weave recommended initiation of handheld computer training in the first year of medical school, with ongoing training during clinical rotations, reporting that the majority of first-year medical students surveyed were unfamiliar with PDA technology and medical applications.¹⁷

We found only 1 randomized-controlled trial that reported educational outcomes. Leung et al. demonstrated that provision of PDAs with clinical decision support software increased students' learning and application of evidence-based medicine, compared with pocket cards and a control group.⁴⁶ However, a follow-up survey by the same investigators revealed that students from all 3 groups used the PDA software infrequently (less than once a week), and their success rate at retrieving the desired information was low (37.6%).⁴³ Greater computer literacy skills, more frequent PDA use, more successful search results, and positive faculty attitudes were associated with students' perceived usefulness of the program.⁴³

Patient Care/Documentation

Most of the studies selected for this review examined medical trainees' use of handheld computers for patient care and documentation.^{2,8,15,16,19,20,22–24,26–28,30,32–44,46,47,49,51–78}

Patient-tracking software is commonly used by medical trainees, although less frequently than PDA-based medical references.^{16,19,24,31,32} In addition to helping with day-to-day patient management, such software can be integrated with the hospital information system. This can save time by allowing students and residents to retrieve laboratory data by synchronizing the PDA with the hospital system, rather than relying on manual retrieval of electronic information or review of printed lab reports.^{54,72,78} Carroll et al. described the development of an electronic charting system in which data entered on PDAs were uploaded to intensive care unit computers.⁵⁴ In a study against historical controls, the electronic system modestly reduced documentation errors in resident progress notes (51.2% vs 61.7%, $P=NS$).⁵⁵

Handheld computers allow medical trainees to document clinical and procedural experience, enabling program directors to more easily compile data and assess the scope of trainees' exposure.^{51,57–59,62–64,66,67,71,73,75–77} MacNeily et al. also

tracked residents' work hours and time allocation.⁶³ A few articles evaluating such PDA-based documentation found it easier to maintain than traditional logbooks.^{53,64,74} However, several concerns were raised about documenting clinical experience via handheld computer, such as inaccurate data entry, the potential to lose data, patient privacy, incomplete trainee participation, technical difficulties with software installation, and the need to provide additional training and support for users unfamiliar with the technology.^{57,58,61,62,65,72} One study of medical students' clinical exposure noted more complete documentation of required patient characteristics with PDA software than with paper cards.⁶¹ Similarly, a randomized study comparing handheld and conventional documentation among orthopedics trainees found more detailed depiction of clinical findings and more accurate diagnostic coding in the handheld group.⁶⁹ However, a report among emergency medicine residents who switched to PDA-based records showed no change in documentation rates for procedures and patient follow-ups.⁵³

Other patient care-related PDA applications include billing, electronic medical record keeping, order entry, and note and prescription writing.^{15,16,20,27,79} Although information is available on the utility of these applications among medical trainees, relatively few analyses have been performed, as such applications are geared toward practicing physicians.

Research Use

Many of the studies cited in this review used PDAs to collect data. However, only 1 paper provided specific information about the feasibility of using PDAs for this purpose in a medical education setting.⁸⁰ Mohl describes how PDAs were used in collecting research data and in transferring files for analysis by collaborators. The ability to store data quickly and accurately helped offset some of the barriers associated with PDA use, such as cost and training time.⁸⁰

Patient Outcomes

Patient outcome data were also limited. We found no studies demonstrating improved clinical outcomes as a result of handheld computer use. In 1 survey of electronic drug reference users, 83% of respondents reported being better able to inform patients about medication use. Half of the respondents estimated that use of the software had prevented at least 1 adverse drug event per week. However, data for this study were self-reported, and actual patient outcomes are unknown.²⁹

DISCUSSION

According to the results of our systematic review, PDAs have become a valuable resource for both medical students and residents over the past decade. Based on the published literature, it appears that up to 70% of medical trainees currently use handhelds. The most popular uses include electronic textbooks, medication reference databases, and medical calculators, although patient-tracking software is also common (see Table 2 for common applications and their websites). Many training programs have incorporated PDAs into medical education and patient care activities, particularly as a vehicle for disseminating references and other course materials, as well as tracking trainees' clinical exposure. While most medical trainees who use handhelds appear comfortable and generally satisfied with them, certain barriers still exist, such as lack of

technical experience, a preference for pen and paper, difficulty handling the small device, and concerns about data loss and security. It appears that initial training and ongoing technical support will be important to increase handheld computer use and maximize its potential in medical education, particularly for physicians who lack familiarity with the devices.

Tablet PCs, which are larger and combine the features of a notepad and laptop computer, may be a viable alternative for those who find PDAs and Pocket PCs difficult to use. However, Tablet PCs have not been adopted widely and were seldom mentioned in the studies reviewed.

With few exceptions, most of the existing literature on PDAs in medical education is descriptive and lacks meaningful outcomes. We found only 1 randomized study of handheld computers with educational outcomes, showing that PDAs facilitated the learning and application of evidence-based medicine.⁴⁶ Another randomized study demonstrated more complete documentation with a PDA-based system, compared with conventional paper-based methods.⁶⁹

Given the high prevalence of PDA use by medical trainees, controlled studies are needed to evaluate how such use impacts both their education and patient care. It should not be assumed that the convenience of accessing information on PDAs improves students' education. It is possible, for example, that handheld computer users become dependent on their "peripheral brain" and do not personally retain as much information as students who rely more on their own memory. This could adversely affect performance on standardized examinations, in which handheld computer use is not allowed. Similarly, since electronic textbooks, medication references, and calculators are the most frequently accessed handheld applications, additional research is needed on how trainees apply these tools to patient care. It is possible that the availability of electronic references reduces the number of educational interactions with attending physicians, consultants, and clinical pharmacists, ultimately reducing the overall educational experience. (Conversely, self-directed learning through a handheld computer may actually be more beneficial than being given the answer by a supervisor or other clinical expert.) Another concern relates to the potential for errors in PDA software, which can be disseminated widely on the internet without quality assurance or peer review, as such errors could impact patient care.

Although many aspects of PDA use in medical education require further research, 4 areas appear most important based on our review of the literature—(1) educational processes, (2) educational outcomes, (3) patient care processes, and (4) patient outcomes. Research on educational processes should include the effect of PDAs on team dynamics during clinical rounds and students' attention during classroom lectures. Another important area is how and when trainees use PDAs to answer clinical questions in real time, either through archived information or wireless internet access. The effect of PDAs on educational outcomes, such as acquisition of knowledge, clinical skills, and test performance, will also require rigorous study. In performing such research, separating out the effects of handheld computers from other educational elements will pose a significant challenge. Studies relating to processes of care should evaluate PDAs as a potential timesaving tool, as they can be synchronized with hospital information systems to facilitate retrieval of patient information. Significant timesavings may have implications in the present era of residency

Table 2. Personal Digital Assistant (PDA) Applications Commonly Used by Medical Trainees

Application	Website
Calculators	
ACS risk	www.statcoder.com
Framingham calculator	www.statcoder.com
MedCalc	www.medcalc.be
MedMath	www.palmgear.com
MentSTAT	goldenratiodesign.com
PregCalc	www.pilotzone.com/palm/preview/34754.html
STAT cardiac clearance	www.statcoder.com
STAT cholesterol	www.statcoder.com
TIMI risk calculator	www.criticalpathways.org.cnchost.com/
Clinical guidelines	
American College of Cardiology	www.acc.org/clinical/palmdownload.htm
American College of Physicians	www.acponline.org/pda/clinical_references.htm
Asthma	hp2010.nhlbi.nih.net/as_palm.htm
HIV/AIDS	www.aidsinfo.nih.gov/mobile/
MedRules	pbrain.hypermart.net/medrules.html
Document readers	
Acrobat reader	www.adobe.com
Documents to go	www.dataviz.com
Electronic medical textbooks	
Five-minute clinical consults	www.skyscape.com
Cecil's	www.us.elsevierhealth.com/Medicine
Ferri's clinical advisor	www.us.elsevierhealth.com/Medicine
Handheldmed	www.handheldmed.com
Harrison's	www.skyscape.com
Skyscape	www.skyscape.com
Washington manual	www.skyscape.com
Medical literature	
Avantgo	www.avantgo.com
Ovid at hand	www.ovid.com
Journal ToGo	www.journaltogo.com
Medication references	
ABX guide	hopkins-abxguide.org
Epocrates	www.epocrates.com
Immunizations	www.immunizationed.org
Lexidrug	www.lexi.com
Medscape Mobile	www.medscape.com
Mobile Micromedex	www.micromedex.com
Physicians' desk reference	www.pdr.net
Patient-Tracker	
Patient tracker	www.handheldmed.com
Patient keeper	www.patientkeeper.com
Pocket chart	www.gemedicalsystems.com
Prescription writing	
iScribe	www.iscribe.com
PocketScript	www.zixcorp.com/ehealth/
University resources	
Arizona Health Sciences	educ/ahsl.Arizona.edu/pda/index.htm
Dalhousie University	www.medicine.dal.ca/palm
Emory University	www.emory.edu/WHSC/grady/inetgrp/hppda.html
Florida State University	med.fsu.edu/library/MedicalDocuments.asp
SUNY Downstate	ect.downstate.edu/support/palm
University of Alberta	www.library.ualberta.ca/pdazone/health/index.cfm
University of Hawaii	hml.org/WWW/pda.html
University of Missouri	hslweb01.umh.edu/ftproot/MUPDAresources.cfm
University of Virginia	www.healthsystem.virginia.edu/internet/library/services/computing/pda/index.cfm
Yale University	www.med.yale.edu/library/pda/

work hour restrictions. Further study on processes of care should also explore PDAs as a vehicle for disseminating evidence-based guideline recommendations, or even as a prompt to perform specific interventions, such as pneumococcal vaccination prior to hospital discharge. Finally, and most importantly, randomized trials are needed to assess the impact of PDA use on patient outcomes, including rates of medication errors. In each of these areas, researchers should include users with different levels of comfort with PDA use and stratify outcomes accordingly.

Limitations of this systematic review relate to the databases searched, the study types available, the physician groups studied in those reports, and biases in the published research. First, we limited our review to the medical literature and did not include human factors or computer engineering research, which is indexed in other databases (e.g., CSA Technology Research Database, LISA: Library and Information Science Abstracts, PsycINFO, and Applied Science & Technology Abstracts). Second, with rare exceptions, most of the studies available for inclusion in the present review were observational or uncontrolled before-after comparisons from single institutions. This limits our ability to draw firm conclusions. Third, some of the studies combined data from medical trainees (medical students, residents, and fellows) and nontrainee physicians (attending physicians). It was not always possible to separate out the attitudes and usage of handhelds by the medical trainees in these studies. Fourth, while we attempted to include a broad range of published research related to PDAs in medical education, unsuccessful institutional efforts may not have been published or presented at conferences, resulting in publication bias. Similarly, response bias among published surveys may have inflated reported rates of PDA use and satisfaction, as regular PDA users may have been more likely to respond than nonusers or occasional users.

Despite these limitations, the present review suggests that handheld computers are an important and evolving part of the medical trainee's resources in medical education and patient care. Incorporating handhelds in medical training provides valuable access to point-of-care information that may positively impact learning and patient care.

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